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Dynamics of Aboveground Mass Hierarchy in Overcrowded Mangrove *Kandelia obovata* Stands on Okinawa Island, Japan

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Abstract

This study examined the aboveground mass dynamics in overcrowded *Kandelia obovata* stands in Manko Wetland, Okinawa Island, Japan, over 8 years. The rank of aboveground mass w was not completely constant as the stands grew, although the values of Spearman's rank correlation coefficient of w significantly differed from zero ($P < 0.01$). Therefore, the mass hierarchy of overcrowded *K. obovata* mangrove stands is dynamic as stands grow, although the changes are not dramatic. The mode of the frequency distribution shifted to the right each year, because the mortality of smaller, suppressed trees was high and the surviving trees continued to grow.

Keywords: Frequency distribution, L-shape, Mortality, Rank, Self-thinning

1. Introduction

When a population of plants first begins to grow, each individual may have access to all of the resources it needs to grow as fast as genetically possible in the environment [1]. However, as time passes, plants continue to grow and begin to compete with each other for resources such as light and nutrients, smaller, weaker plants become dominated by larger, stronger plants, and eventually die [2]. Such intense competition within stands leads to self-thinning [3–4], a natural process whereby the number of trees per unit area decreases as the average mass of trees increases over time. Self-thinning is considered as one of the most important plant

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demographic processes and has important implications for the ecology of overcrowded plant populations. Self-thinning is eventually accompanied by concomitant changes in the dynamics of stand structure over time.

In Manko Wetland, Okinawa Island, Japan, *Kandelia obovata* (S., L.) Yong is the most dominant mangrove species. Knowledge of the forest structure through the dynamics of aboveground mass is necessary for the management of the overcrowded *K. obovata* stands. Therefore, we examined the dynamics of the aboveground mass hierarchy over 8 years.

2. Materials and methods

2.1. Study site

The study was conducted in an overcrowded forest of *Kandelia obovata* (S., L.) Yong in Manko Wetland, located in the southern part of Okinawa Island, Japan (26°11'N, 127°40'E). Based on data from 2000 to 2009 obtained from the Okinawa Meteorological Agency, the warm index [5] was 219.8 ± 15.4 (SE) °C month, indicating that this area belongs to the subtropical region. During the study period, monthly mean maximum temperature was 25.0 ± 0.1°C in July, and monthly mean minimum temperature was 21.0 ± 0.1°C in February. Mean annual precipitation was 2177.4 ± 156.7 mm yr^{-1}. The study area is a brackish tidal flat, covering an area of 58 ha at low tide. The mud flat area is mainly composed of clay particles. The wetland receives regular tidal inundation and some freshwater through run-off from adjacent areas [6]. In addition to the *K. obovata* forest, a few patches of *Rhizophora stylosa* Griff. and *Bruguiera gymnorrhiza* (L.) Lamk. are also present.

2.2. Tree census and estimation of aboveground mass

A 125-m-long, 5-m-wide belt-transect was established in the *K. obovata* forest perpendicular to river flow. The transect was divided into 25 subplots (5 m × 5 m each), each of which consisted of a growing and crowded cohort [7], and all individuals in the subplots were numbered. In each subplot, tree height H (m) and stem diameter $D_{0.1\mathrm{H}}$ (cm) at $H/10$ were measured every summer from 2004 to 2011. Mean H and mean $D_{0.1\mathrm{H}}$ of every subplot ranged from 2.17 to 3.76 m and 2.80 to 4.84 cm, respectively, as of 2010. Aboveground mass w (kg) was estimated by inputting the tree census results into the following allometric relationship obtained by Khan et al. [6] at Manko Wetland for the overcrowded *K. obovata* forest: $w = 0.03923\,(D_{0.1\mathrm{H}}^{2} H)^{1.022}$. The aboveground mass data were arranged by subplot every year.

2.3. Statistical analysis

After trees in a subplot were ranked in order of aboveground mass w for every year, Spearman's rank correlation coefficient r_s was calculated for the rank of w to evaluate the degree of concordance in rank among years in each subplot. When $r_s = +1$, the ranks of trees are the same among years; when $r_s = 0.0$, the ranks of trees are completely different among years; and when $r_s = -1$, the ranks of trees are completely opposite among years. The value of r_s was obtained for each subplot for the first year to the second year, the first year to the third year, the first year to the fourth year, and so on. In the calculation of r_s, dead trees were excluded.

The skewness b_1 of the frequency distribution of w in each subplot was also calculated over the study period. If the b_1 value is positive, the frequency distribution is L-shaped; if the b_1 value is negative, the frequency distribution is J-shaped; and if the b_1 value is zero, the frequency distribution is bell-shaped.

3. Results and discussion

Figure 1 shows Spearman's rank correlation coefficient r_s of aboveground mass w for the first year to the second year (open circles), third year (filled circles), fourth year (open triangles), fifth year (closed triangles), sixth year (open diamonds), seventh year (closed diamonds), and eighth year (open squares). The positive values of r_s did not significantly differ from zero ($P < 0.01$), but decreased significantly with increasing mean aboveground mass $\overline{w}$ ($r = 0.63$, $P < 0.01$). As shown in Fig. 2, the rank of a tree was not completely constant and could change throughout its lifetime.

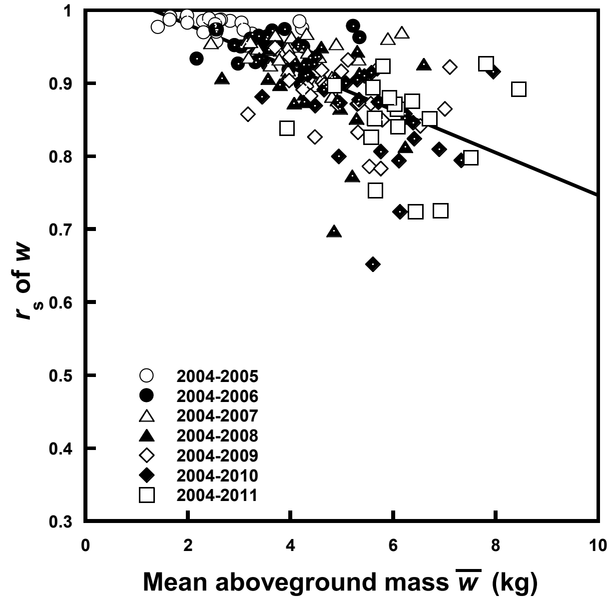

Fig. 1. Relationship of Sperman's rank correlation coefficient r_s of aboveground mass w to mean aboveground mass $\overline{w}$. The straight line indicates the regression line ($r = 0.63$, $P < 0.01$).

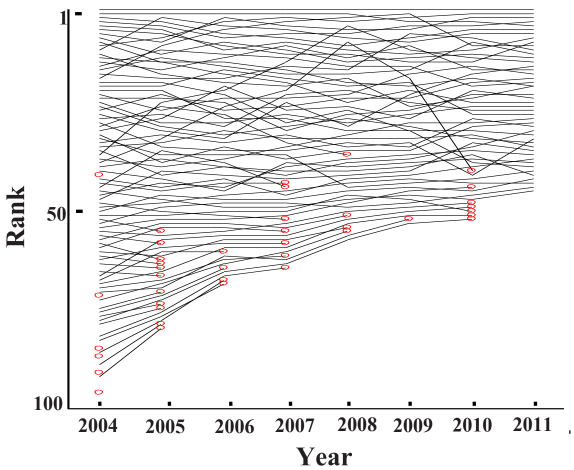

Fig. 2. An example of the time trends of the rank in aboveground mass of trees in a subplot over 8 years. The open circles are trees that died during the ensuing year.

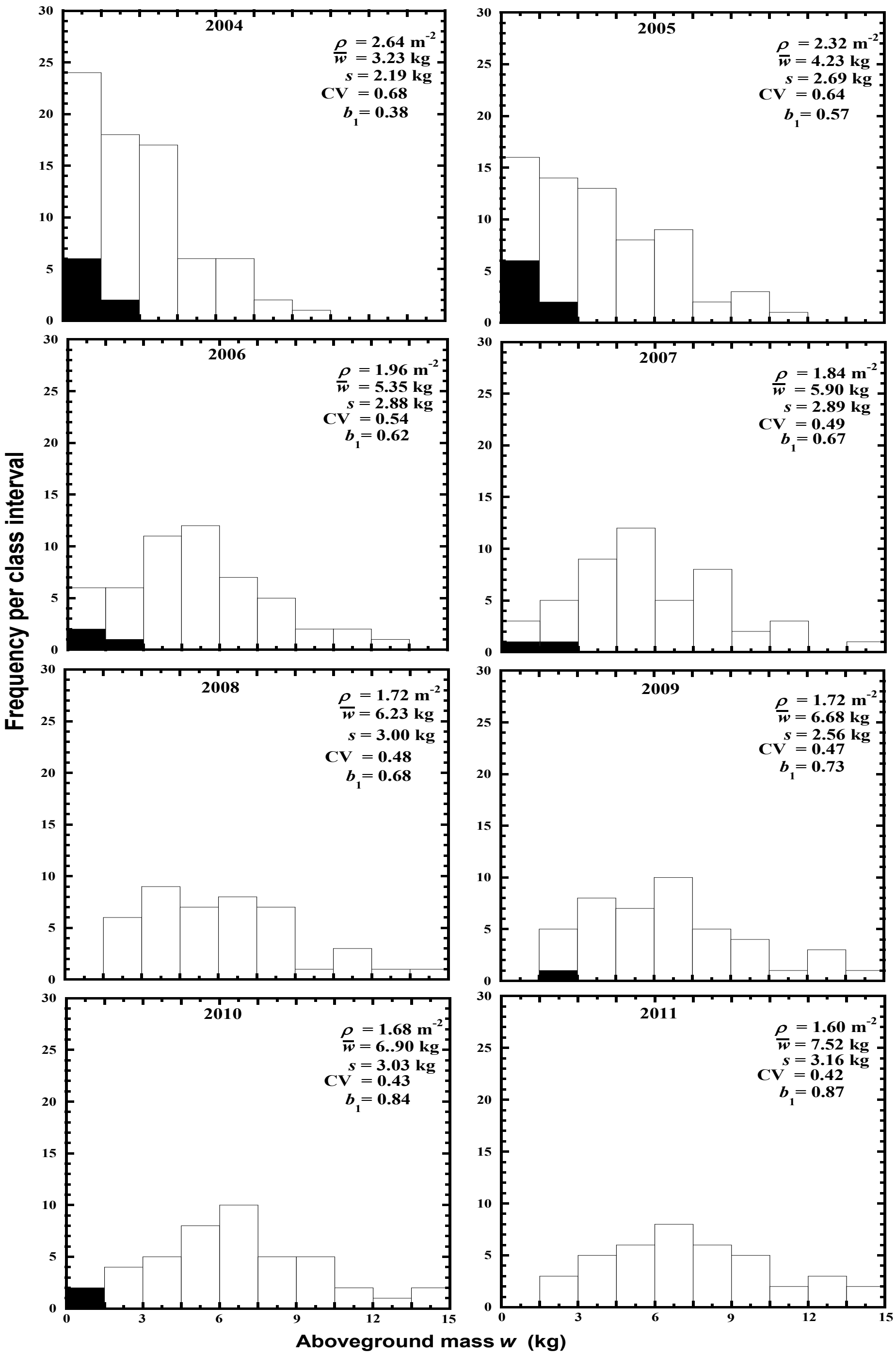

Fig. 3. An example of the transition of the frequency distributions of aboveground mass w in a subplot over 8 years (2004-2011). Open columns, living trees; filled columns, trees that died during the ensuing year. ρ, population density; $\overline{w}$, mean; s, standard deviation; CV, coefficient of variation ($= s / w$); b_1, skewness.

Figure 3 presents an example of the transition of the frequency distributions of w in a subplot. The tree that died during the ensuing year belonged to the lower classes (filled columns) of the frequency distributions.

Figure 4 illustrates the relationship between the skewness b_1 of the frequency distribution of w to its mean $\overline{w}$. All b_1 values of the frequency distribution of w were positive, indicating that the frequency distribution of w was L-shaped. The values of b_1 did not change significantly as the stand grew (r = 0.13, $P > 0.05$), which means that the frequency distribution of w is stable in the L-shape even if the stands grow.

Kikuzawa [8] assumed that the rank of mass remains constant over time; however, our results suggest that the rank of mass can change as stands grow, although values of Spearman's rank correlation coefficient r_s of w significantly differed from zero as mentioned above. In fact, as illustrated in Fig. 2, most ranks of trees in w changed over the 8 years of the study. These results suggest that the aboveground mass hierarchy of the overcrowded *K. obovata* stands was dynamic as the stands grew, although the changes were not dramatic.

The frequency distribution of w was retained as an L-shape throughout the study period. The mode of the frequency distribution shifted to the right each year, because the mortality of suppressed trees was high and the dominant trees continued to grow. Analuddin et al. [7] also observed an L-shaped frequency distribution of w in overcrowded *K. obovata* stands on Okinawa Island, Japan. Similar results have also been reported for terrestrial plant populations [9–11].

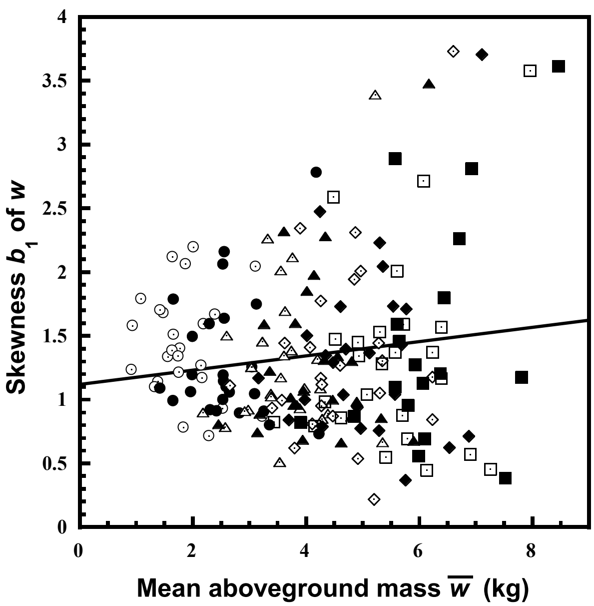

Fig. 4. Relationship of skewness b_1 of the frequency distribution of aboveground mass w to its mean $\overline{w}$. Symbols are the same as in Fig. 1. The straight line shows the regression line (r = 0.13, $P > 0.05$).

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